QUANTIFYING C STOCKS IN HIGH-YIELD, SHORT-ROTATION WOODY CROP PRODUCTION SYSTEMS FOR FOREST AND BIOENERGY VALUES AND CO_2 EMISSION REDUCTION

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Abstract

Short-rotation woody crop (SRWC) systems sequester atmospheric CO_2 in their fibre and surrounding soil. Studies have promoted the carbon (C) sequestration potential of concentrated SRWC systems, but most examine only aboveground biomass and soil organic carbon (SOC) stocks on young systems (<6 years). The objectives of this study were, (a) to quantify above- and belowground carbon stocks within an 8-year-old concentrated SRWC system and (b) to compare SOC stocks between SRWC systems and an adjacent conventional agricultural system. Fibre C accumulations among clones in concentrated SRWC systems ranged from 1.02 to 5.34 t y^{-1}. SOC stocks for concentrated SRWC averaged 78.66 t C ha^{-1} (0-30cm), with an increase of 1.16 t C ha^{-1} y^{-1} compared to the baseline measurements in 2009 (69.42 t C ha^{-1}). SOC stocks for the agricultural system (0-30cm) have dropped to 63.80 t C ha^{-1}, averaging a loss of 0.70 t C ha^{-1} y^{-1} since 2009.

Keywords: bioenergy; carbon sequestration; carbon stocks, climate change mitigation, short-rotation woody crops; soil organic carbon

Introduction

The Canadian government has turned its efforts towards carbon pricing strategies leading to the adoption of the 2017 cap-and-trade program in the province of Ontario (ECCC 2016). This program meets the Paris Agreement’s emphasis on efficient carbon pricing, but also provides an incentive for the development of carbon sinks and reservoirs. Short rotation woody crops (SRWC) have attracted the focus of both private and public enterprise for both their potential as a bioenergy source and their value as a long-term carbon (C) sink by sequestration of atmospheric CO_2 into tree biomass and soils (Montagnini and Nair 2004). Moreover, concentrated SRWC systems have the potential to enhance C sequestration even further due to planting densities of ~20 000 stools ha^{-1} (Cardinael et al. 2012).

SRWC systems sequester atmospheric CO_2 in their fibre, as well as in the soil through the decomposition of litterfall and fine-root turnover. Recent studies have promoted the carbon sequestration potential (CSP) of concentrated SRWC systems, but most examine only aboveground biomass and soil organic carbon stocks on young systems (6 years or less). More robust and longer term studies quantifying system level carbon stocks in concentrated SRWC systems are lacking for the temperate region. The objectives of this study are therefore, (a) to quantify above- and belowground C stocks within an 8-year-old concentrated SRWC system, (b) to compare SOC stocks between various SRWC systems, a conventionally managed agricultural system, and an old growth forest, all adjacent to one another (Figure 1). Under Ontario’s new cap-and-trade program, biomass growers may potentially earn offset carbon credits as compensation for carbon sequestration and gain additional revenue through trading of their respective credits within the market (ECCC 2016). The results from this study will provide biomass growers with better information regarding the CSP of concentrated SRWC systems in southern Ontario, enhancing the economic outlook of such systems. Furthermore, this research may also contribute towards policies promoting concentrated SRWC systems based on their environmental benefits, in addition to their bioenergy potential.

Figure 1: Study sampling locations at the Guelph Agroforestry Research Site, Guelph, Ontario, Canada.

Materials and methods

The experimental SRWC field site is located at the University of Guelph Agroforestry Research Station in Guelph, Ontario (Figure 1). In 2009, concentrated SRWC plantations (20,000 stems ha^{-1}) of *Populus* (*2293-19, DN-136, DN-154, and NM-6*) and *Salix* (*India, SX64, SX67, and Viminalis)* were established on Class 3-4 agricultural land, which is denoted by the Canadian Land Inventory as land with moderate to severe limitations and restricted crop choice. This study featured a 8 x 2 factorial treatment design (clone x design), arranged in a Randomized Complete Block Design with three replications for each clone x design combination (3 x 8 x 2 = 48 plots). Clone cuttings were planted under two different designs: two-row (2R) and three-row (3R). In 2R plots, spacing adhered to the European double-row design (Cardinael et al. 2012). In 3R plots, spacing within each triple row was 0.75 m, while triple rows were spaced 2.00 m apart and each stool within each row was 0.60 m apart. The concentrated SRWC systems were coppiced following their initial growing season in 2009, and commercially harvested every three years (2012 and 2015).

System fibre C accumulation

Aboveground biomass was assessed in the fall of 2015 (cycle 2 harvest), while belowground biomass and leaf litter biomass were assessed in the fall of 2016. Moisture content was assessed and above- and below-ground biomass values were converted into oven dry tonnes per hectare per year (odt ha^{-1} yr^{-1}). For the calculation purposes of this paper, a value 47.7% was used to represent the proportion of carbon in all tree components (Thomas and Martin 2012). Annual aboveground fibre accumulation was calculated by dividing total aboveground biomass by three to obtain the average annual accumulation for the second growing cycle. Annual belowground fibre accumulation was calculated by dividing the total belowground biomass by 8, which represents the age of root system. Annual fine-root turnover (FRT) was estimated at 50% of the annual litterfall C input (Peichl et al. 2006).

Soil organic carbon

Soils within the treatment blocks were randomly sampled in both 2009 (0-30cm) and 2016 (0-30cm and 30-60cm) using a soil auger. For comparative purposes, soil samples were also collected at four other adjacent fields, at depth of 0-30cm and 30-60cm, under three different land-uses, including a conventionally managed agricultural field on a corn-soybean-wheat crop rotation, two SRWC afforestation sites (established in 2005 and 2009, respectively) planted with a variety of poplar clones, as well as a nearby old growth forest (University of Guelph Arboretum; Figure 1). Samples were processed in lab and analyzed using the combustion method with a LECO CR-12 Carbon Analyzer as described by Cardinael et al. (2012). Triplicate bulk density samples were also obtained for each land-use at 0-30cm and 30-60cm depths to allow carbon stocks to be calculated for each depth. The value of SOC gain was divided by years of growth to determine the average annual rate of C addition to the soil.

Results

Annual system fibre C accumulation in SRWC systems

Differences in annual system fibre C accumulation were not found to be significantly influenced by design and ranged from 1.02 t C ha^{-1} for NM6 to 5.34 t C ha^{-1} for SX64 (Figure 2). Annual aboveground biomass C accumulations accounted for 59.6 to 73.9% of total annual fibre C accumulations, while belowground biomass C accumulations accounted for 17.3 to 32.2% of total annual fibre C accumulations. Leaf litter C inputs accounted for 1.5 to 6.5% of total annual fibre C accumulations, while estimated fine-root turnover inputs accounted for 0.8 to 3.2% of total annual fibre C accumulations.

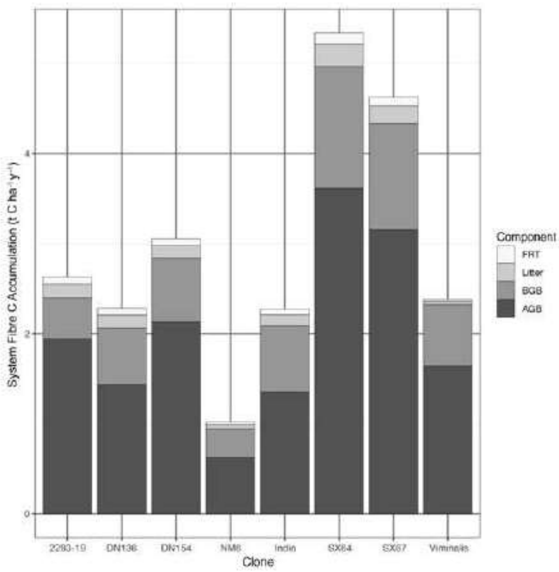

Figure 2: Estimated annual fibre C (t ha^{-1}) accumulation from aboveground biomass (AGB), belowground biomass (BGB), litter, and fine-root turnover (FRT) for eight short-rotation clones in an 8-year-old concentrated SRWC production system in southern Ontario, Canada (n=6).

Soil carbon in SRWC systems

SOC was significantly higher ($p<0.001$) at a depth of 0-30cm (2.02 ± 0.06%) than at a depth of 30-60cm (1.69% ± 0.06; see Table 1). Average SOC in 2016 at a depth of 0-30cm (2.02 ± 0.06%) was also significantly higher ($p<0.001$) than baseline SOC measured in 2009 (1.78 ± 0.03%; data not presented). When factoring in bulk density, SOC stocks were not found to be significantly different between treatment combinations but ranged from 71.29 to 83.77 t C ha^{-1} at a depth of 0-30cm (mean= 78.66), while ranging from 71.16 to 88.91 t C ha^{-1} at a depth of 30-60cm (mean= 79.01). SOC stocks at 0-30cm depth in 2016 (78.66 t C ha^{-1}) were found to be significantly higher ($p<0.001$) than 2009 baseline SOC stocks (69.42 t C ha^{-1}), with these systems sequestering an average of 1.16 t C ha^{-1} y^{-1} during the first eight years following establishment.

Table 1: Comparison of mean soil organic carbon (SOC) measurements at two depths (0-30cm and 30-60cm) for five land-use systems in southern Ontario, Canada (Afforestation established in 2005, n=9; afforestation established in 2009, n=9; agricultural field, n=3; old growth forest, n=3; concentrated short rotation woody crops (SRWC) established in 2009, n=24).

	SOC (%)		SOC (t C ha^{-1})	
Land-use	0-30cm	30-60cm	0-30cm	30-60cm
Afforestation (2005)	2.15 (0.07) ^{bx}	1.61 (0.08) ^{by}	70.99 (2.34) ^{bcx}	63.73 (2.98) ^{ax}
Afforestation (2009)	1.72 (0.04) ^{by}	2.01 (0.09) ^{abx}	61.94 (1.55) ^{cy}	79.59 (3.76) ^{ax}
Agricultural Field (2016)	1.64 (0.18) ^{bx}	1.70 (0.13) ^{bx}	63.80 (7.04) ^{bcx}	79.56 (6.21) ^{ax}
Old Growth Forest	**3.35 (0.61)** ^{ax}	**2.53 (0.11)** ^{ax}	**104.06 (8.88)** ^{ax}	86.41 (3.05) ^{ax}
Concentrated SRWC (2009)	2.02 (0.06) ^{bx}	1.69 (0.06) ^{by}	78.66 (2.31) ^{bx}	79.01 (2.74) ^{ax}

*Superscripts (a-b) indicate significant differences between land-uses (down columns), as determined by one-way ANOVA and subsequent Tukey HSD test ($p<0.05$). The highest ranking value for the land-use comparison at each depth is indicated in bold. Additionally, superscripts (x-y) indicate significant differences between depths (0-30cm vs 30-60cm) for each land-use, as determined by respective t-tests ($p<0.05$).

Land-use Comparison

SOC at a depth of 0-30cm ranged from 1.64% for the agricultural field to 3.35% for the old growth forest, with the concentrated SRWC having 2.02% SOC (Table 1). At a depth of 30-60cm, SOC ranged from 1.61% in the 2005 planted afforestation plots to 2.53% for the old growth forest, with the concentrated SRWC having 1.69% SOC. When factoring in bulk density, SOC stocks at 0-30cm ranged from 61.94 t C ha^{-1} in the 2009 planted afforestation to 104.06 t C ha^{-1} in the old growth forest, with the concentrated SRWC having 78.66 t C ha^{-1}. SOC stocks at 30-60cm ranged from 63.73 t C ha^{-1} in the 2005 planted afforestation to 86.41 t C ha^{-1} in the old growth forest, with the concentrated SRWC having 79.01 t C ha^{-1}.

Discussion

Overall, annual system fibre C accumulation averaged from 1.02 to 5.34 t C ha^{-1} y^{-1} across all tested clones (Figure 2). SOC stocks for concentrated SRWC averaged 78.66 t C ha^{-1} from 0-30cm in depth, with an average increase of 9.24 t C ha^{-1} (1.16 t C ha^{-1} y^{-1}) sequestered compared to the baseline measurements in 2009 (69.42 t C ha^{-1}) (Table 1). In contrast, SOC stocks for the agricultural field have dropped to 63.80 t C ha^{-1} from 0-30cm in depth, meaning an average loss of 0.70 t C ha^{-1} y^{-1} compared to 2009 levels. Differences were less pronounced and non-significant between land-uses at a depth of 30-60cm.

Results from this study suggest that selecting high performing clones (i.e. SX64), even on marginal lands, can enhance system level carbon sequestration by more than 5 t C ha^{-1} y^{-1} in above- and belowground system fibre, in addition to more than 1 t C ha^{-1} y^{-1} in soil as SOC. Over the plantation lifespan (~21 years), this concentrated SRWC system may be expected to sequester nearly 25 t C ha^{-1} in SOC alone. These findings are significant as the monetization of carbon may provide an additional revenue stream to biomass growers, further enhancing adoption. Furthermore, concentrated SRWC systems may be implemented within or in conjunction with more traditional agroforestry systems to derive beneficial ecosystem services, including carbon sequestration, while producing harvestable biomass on shorter (~3 year rotations) timescales. Additional research is required to examine such systems in later stages of growth (cycles 5-7), with attention also paid to belowground root decomposition following the productive lifespan of such plantations.

References

Cardinael R, Thevathasan NV, Gordon AM, Clinch R, Mohammed I, Sidders D (2012) Growing woody biomass for bioenergy in a tree-based intercropping system in southern Ontario, Canada. Agrofor Syst 86: 279-286.

Environment and Climate Change Canada [ECCC] (2016) Canada's Second Biennial Report on Climate Change. Ottawa: Government of Canada. https://www.ec.gc.ca/GES-GHG/default.asp?lang=Enandn=02D095CB-1 (accessed 3/04/2017).

Montagnini F, Nair PKR (2004) Carbon sequestration: An underexploited environmental benefit of agroforestry systems. Agrofor Syst 61: 281-295.

Peichl M, Thevathasan NV, Gordon AM, Huss J, Abohassan RA (2006) Carbon sequestration potentials in temperate tree-based intercropping systems, southern Ontario, Canada. Agrofor Syst 66: 243-257

Thomas SC, Martin AR (2012) Carbon content of tree tissues: a synthesis. Forests 3: 332-352.